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SCHENECTADY, NEW YORK

Quarterly Report No. 3

STUDY OF DYNAMIC AND STATIC SEALS FOR LIQUID ROCKET ENGINES

For Period December 30, 1968 to March 30, 1969

NASA Contract No. NAS 7-434 PHASE III

Prepared for

Chief, Liquid Propulsion Technology, RPL
National Aeronautics and Space Administration
Washington, D.C.

QUARTERLY REPORT NO. 3

DECEMBER 30, 1968 to MARCH 30, 1969

STUDY OF DYNAMIC AND STATIC SEALS FOR LIQUID ROCKET ENGINES

APRIL 15, 1969

CONTRIBUTORS: J. A. Findlay
H. J. Sneck

TO: Chief, Liquid Propulsion Technology, RPL
Office of Advanced Research and Technology
NASA Headquarters
Washington, D. C. 20546

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PREPARED BY: Research and Development Center
General Electric Company
Schenectady, New York 12301

CONTRACTING COMPONENT: Missile and Space Division
General Electric Company
Philadelphia, Pennsylvania

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PROJECT STATUS REPORT

PROJECT TITLE: STUDY OF DYNAMIC AND STATIC SEALS FOR LIQUID ROCKET ENGINES

CONTRACT NUMBER: NAS 7-434 PHASE III

QUARTERLY PROGRESS REPORT NUMBER 3

REPORT PERIOD: DECEMBER 30, 1968 - MARCH 30, 1969

SPONSOR: NASA-RPL WASHINGTON, (MSD - GENERAL ELECTRIC COMPANY)

TECHNICAL MONITOR: JET PROPULSION LABORATORY

R&DC COMPONENT: MECHANICAL ENGINEERING LABORATORY

Technical Specifications of Sponsoring Component

The objective of this program is to advance the technology of dynamic and static seals for liquid rocket engines. A study of the fundamentals of sealing processes is to be carried out in order to provide the understanding necessary to formulate design criteria for seals in future liquid rocket engines.

SCHEDULED COMPLETION OF TECHNICAL WORK: JUNE 30, 1969

FINAL DRAFT: JULY 31, 1969

PERCENT CONTRACT FUNDS AND MAN-HOURS EXPENDED TO DATE: Dollars 58% Man-Hours 60%

TECHNICAL CONTRIBUTORS: J. A. Findlay
H. J. Sneck

TECHNICAL STATUS OF ENGINEERING WORK: (See Accompanying Report)

John A. Findlay

J. A. Findlay
Mechanical Engineer - NASA Seals
Mechanical Development Unit
Mechanical Equipment Branch
Mechanical Engineering Laboratory
Building 37, Room 1020
TEL: 518*374-2211, Ext. 5-4230

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NAS 7-434 PHASE III

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I. SUMMARY

This report presents the status of technical work performed during the third quarter period of NASA Contract NAS 7-434 Phase III. The work on this contract is of a fundamental nature and is concerned with furthering the understanding and solving of static and dynamic sealing problems, particularly as they apply to liquid rocket engines.

The third quarter work was devoted to: (1) Evaluating and organizing the seal design information on rotary shaft seals, particularly the mechanical face seal, and (2) modifying the analysis of the labyrinth seal problem to improve the model.

Work on the Design Guide has focused on the design parameters of rotary seals and organizing the available material in a more usable form. There is more theoretical design and performance data on the non-contacting rotary seals, whereas the mechanical face seal is more widely used. Fortunately, because of its wide usage, there is more experience with face seals and a number of well written design papers on this.

The analysis of labyrinth seals for explosive squibs has undergone further modifications in an effort to obtain approximate solutions. The assumptions regarding the expansion of the fluid from the land to the groove had to be changed somewhat. There is not much information on this problem in the literature and the solution continues to proceed through a process of assumption, evaluation, and modification.

The technical work on this contract is conducted by personnel of the Research and Development Center, General Electric Company. Project Engineer is J. A. Findlay and the Project Manager is J. A. Bain.

NASA Technical Manager is Mr. Richard S. Weiner, Jet Propulsion Laboratory, Pasadena, California. NASA Project Manager is Mr. Frank E. Compitello, Liquid Propulsion Technology, Rocket Propulsion Laboratory, NASA Headquarters, Washington, D. C.

II. DESCRIPTION OF PROGRAM

The technical work described in this report is being performed by the Research and Development Center, General Electric Company, for the National Aeronautics and Space Administration under Contract NAS 7-434. The fundamental technical effort is intended to advance the technology of seals and sealing mechanisms in order to p rovide the understanding necessary to formulate seal design criteria for future liquid rocket engines. The present effort is a continuation of the work done in Phase II with the emphasis now being on an overall seal design guide and analysis of a labyrinth seal for service in high speed, hot gas, short stroke pistons.

A brief outline of the Project Plan for the current work phase is given in Quarterly Report No. 1.

III. DISCUSSION OF RESULTS

A. General

This quarterly report covers the technical activities performed during the period December 30, 1968 to March 30, 1969.

The task designations are taken from the contract work statement and are in accordance with the headings used in the Project Work Plan. This portion of the report is intended to provide a discussion of the important accomplishments under each task for this report period, and indicates the overall relationships in terms of the program objectives.

B. Task 1: Preparation of the Design Guide

Writing of that portion of the Design Guide dealing with rotary shaft seals is in progress. The chapter on mechanical face seals is being written first since this is the most widely used type and more information is available on this seal. However, the design data available on non-contacting seals has a better theoretical basis and is more complete from this point of view. The face seal design can take so many forms, because of its varied uses, that it is difficult to cover all of them or to give a particular design approach. There are a number of good papers on face seal design, construction and materials available, however.

Updating of the Bibliography is being worked on at the present. This effort also serves the purpose of collecting more of the recent seals papers for inclusion in the Design Guide.

C. Task 2: Design Guide Support

The effort on this task to date has been primarily on the seal computer programs. During this report period the numerical equations for the spiral groove face seal were set up but there are no plans at present to include them in the seal computer program.

D. Task 3: Labyrinth Seal Analysis

The results from previous calculations made, under this study, for a single land-groove combination have been evaluated and modifications deemed necessary. These modifications have been made and the programming is now being checked out. These modifications involve the expansion of the gases from the land to the groove. The one dimensional approach used previously did not appear to be adequate for the deep groove case.

Results indicate that the gas velocity entering the second land is higher than the velocity at the inlet to the first land. This would at first seem to be a worse case than the straight through clearance seal. However, the velocity is lower in the groove and the transit time across a land-groove set is, therefore, longer than for the straight through seal. Unfortunately, this increase in transit time is not of the order-of-magnitude desired. It may turn out, however, that for multiple land-groove sets that this time will be further increased. The results at this point are not sufficient as yet to allow speculation on this.

APPENDIX A

SEALS DESIGN GUIDE

By

J. A. Findlay

As stated in the last quarterly report, the effort during this period has been directed toward rotary seals. Pertinent material has been gathered together and categorized as to seal type. The basic chapter outlines for these seals have been organized and the chapter on face seals is in the writing.

The available material on non-contacting seals has a strong theoretical base, and although not complete in every detail, does represent a good basis for design. The design data available in the literature on mechanical face seals is based more on experience than theory. There are some basic theoretical concepts upon which to base a face seal design, however. Also, there are many theoretical and experimental papers on face seals. Even though this is the case, there has been some difficulty in establishing a theoretical basis for face seal design and in developing a reliable method for calculating performance. Apparently the reason for this is that interfacial geometry is an important parameter in face seal operation and this geometry is somewhat uncontrolled and changeable. This is perhaps the major reason for the recent popularity in non-contacting, hydrodynamic and hydrostatic face seals. The interfacial geometry of these seals is known and is established by design to give the desired performance.

Because of their inherent characteristics, the carbon graphite face seal does perform well in many applications. One of the most important factors in their design is material selection. A good deal has been written on this subject. In fact, so much has been written on face seals that it is a sizeable job to evaluate it all.

The design guide on face seals is starting with a description of the basic seal and the parameters which affect its performance. This is followed by a discussion on materials and a review of face seal theory. Descriptions of some of the various face seal arrangements will also be given.

Future effort will be concentrated on finishing the face seal portion of the guide and then the chapters on other rotary seal types.

APPENDIX B

LABYRINTH SEAL ANALYSIS

By

H. J. Sneck

At the time of the last quarterly report, the analysis of the unsteady flow through the labyrinth seal had been completed up to the end of the first land. This portion of the seal is analogous to a shock tube, and hence, is a generally well understood transient flow problem. The analyses of the flow transition from the first land to the first groove (step-down) had also been successfully completed for relatively shallow grooves. An attempt to analyze the flow transition from the first groove to the second land (step-up) had encountered certain apparent difficulties which were then under investigation. The major difficulty with the analysis was the fact that it yielded a higher fluid velocity entering the second land than entering the first land. The unacceptability of this result was based on the intuitive assumption that the flow velocity should decrease moving downstream away from the entrance.

Subsequent study of this unexpected acceleration has not produced any rational explanation which supports this intuitive assumption. Quite the contrary. Every attempt to refine the analysis, in the hope that refinements would produce the expected deceleration, always resulted instead in an acceleration. In the absense of contradictory experimental evidence, it must be concluded that this is indeed the case and also that it is an important factor in the transient performance of the labyrinth seal.

Having produced convincing theoretical evidence that the unexpected result was acceptable, a further refinement has been introduced into the analysis which now permits the investigation of both shallow and deep grooves. The shallow groove theory (developed earlier) assumes that the one-dimensional uniform flow through the land area is quickly re-established in the groove area. For deep grooves, this is obviously not accurate since the supersonic flow leaving the first land probably acts more like an under-expanded jet exhausting from a nozzle.

Relatively simple methods are available which yield the maximum size of the jet as it expands after leaving the land area. If this area is larger than the groove depth, it is reasonable to assume that one-dimensional uniform flow is re-established on the groove area and the shallow groove theory is appropriate. If this area is smaller than the groove depth, the flow from the groove area probably behaves more like an under-expanded jet which is then dissipated by viscous effects to nearly the local stagnation temperature and nearly zero velocity. Under these conditions, the first groove behaves more or less like the original explosion chamber, filling very rapidly with a high temperature quiescent gas which spills over into the second land area producing a shock wave similar to the one in the first land area.

A computer program which recognizes the difference between a shallow and deep groove has been written and is now in check-out prior to initialing sample parameter study calculations.

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August 12, 1968

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2	Chief, Liquid Propulsion Technology Program NASA - Code RPL Washington, D. C. 20546
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<u>MISSILE AND SPACE DIVISION</u>

Mr. D. G. Flom
General Electric Company
P. O. Box 8555
M9132
Philadelphia, Pennsylvania 19101

Mr. E. M. Conaway
Advanced Requirements Planning Operation
Valley Forge Space Technology Center
General Electric Company
Room M3041
P. O. Box 8555
Philadelphia, Pennsylvania 19101

Mr. A. D. Cohen - Room U-7216
General Electric Company
Missile and Space Division
Valley Forge Space Technology Center
P. O. Box 8555
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